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Analyzing the Impact of Official Development Assistance and Economic growth on Environmental Pollution in Case of Pakistan

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This study examines the Environmental Kuznets Curve in Pakistan from 1996 to 2022. Unit root tests show all variables are integrated at order 1, except urbanization, which is at both orders. Employing auto regressive distributed lagged models, the study finds that foreign direct investment and economic growth increase carbon emissions in the long run, while trade and urbanization decrease them. A non-linear model reveals a U-shaped relationship between net official development assistance and carbon emissions. Policy implications suggest integrating official development assistance into sustainable development initiatives, such as capacity-building programs and policy reforms, to promote sustainable practices and carbon emission reduction.

Keywords: Environmental Kuznets curve; net official development assistance; non-linear auto-regressive distributed lagged.

INTRODUCTION

Globally, the pressing concern for environmentalists and researchers is the ongoing deterioration in environmental quality and climate change. The persistent increase in greenhouse gases (GHG) emission is held responsible for the adverse changes in climate and environment. Currently, the international organizations, governments, political scientists, energy experts, and environmental economists are emphasizing the importance of clean energy for environmental sustainability.

Additionally, clean energy is recognized as the 17th Sustainable Development Goal (SDG) for addressing environmental issues. The Kyoto Protocol signed in 1997 and implemented in 2005 urged for collective efforts for reduction in pollution emissions globally. But, the present rise in carbon emissions (CO2), holding major share ((90%) of the GHG is still a big challenge for both developing and developed countries Du & Belharouak, 2019). According to the International Energy Agency (IEA) report of 2019, carbon dioxide emissions from energy consumption are the highest among greenhouse gases accounting for 90% of the total. In Pakistan, carbon emissions from energy sector are 25%, manufacturing (21%), agriculture (24%), vehicle combustion (14%), other energy-related sources (10%), and buildings (6%). The persistent rising demand of energy use has generated two critical issues in Pakistan: the severe energy crisis and tremendous CO2 emissions. This highlights the pressing need for global discussions on strategies to reduce CO2 emissions and shift toward a low-carbon economy. In the last two decades, Pakistan has consistently ranked in the top ten global countries where climate change has significantly and negatively impacted the environment .

According to the Asian Development Bank climate change report, Pakistan has experienced an annual mean temperature rise of 0.5°C, leading to adverse effects on human health, decreased crop productivity, reduced river flow, increased occurrences of droughts and heat waves, and negative impacts on hydropower generation (Ahmad *et al.*, 2020; Abbas, S. 2022; Pakistan incurred a substantial economic loss equivalent to per unit 0.53% of its gross domestic product (GDP), as a result of rapid climate changes between 1999 and 2018. Thus, energy consumption, environmental sustainability, and economic growth are highly debated topics among research community.

The "German Watch Report" on Pakistan over last 20 years declared it on 10th position among 10 countries where adverse impacts on the environments were noted. Asian Development Bank (ADB) report on Pakistani highlighted annual average rise of temperature by 0.5°C which led to health issues, productivity loss in agriculture sector, droughts, rivers' flow, heat waves and bad influences on hydropower generation

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(Ahmad *et al.*, 2020. Pakistan incurred 0.53 per unit of GDP equivalent to $3792.52 as an economic loss due to fast climatic ups and downs during 1999-2018 (Faheem, M. *at al.*, 2023).

A mitigate of CO2 emissions has been kept on top agenda in the Kyoto Protocol green development mechanism. In this respect, global efforts are necessary aiming at sustainable environment. Where official development assistance (ODA) promotes the growth and welfare of the developing economies, it can play a critical role in fighting against climate change because human activities for development purpose also affect sustainable environment. Developing economies are less responsive to environmental change than developed economies because of taking time for appropriate actions against environmental problem and depending on such industries, which are the main reasons of environmental pollution (Kang, M. Y., & Guerin, D. A. 2009). Therefore, Michaelowa and Michaelowa (2007) have stated that the role of ODA is changing due to rising climate issues. Organization for Economic Cooperation and Development) has also suggested incorporating environmental problem with development targets. However, there are only few studies which covered the use of ODA to overcome environmental issues. According to Awan, A. G. (2013), maintaining environmental quality should be tracked to meet sustainable development goal. Therefore, this study will investigate the impact of ODA on carbon emissions.

The idea of globalization was started from the concept of free trade among nations as presented by Adam Smith. Production and trade were the foundation of output growth across the worldwide history. This scenario brought about environment changes in the end of 19th century and governments realized the need of environmental protection and further, environmental degradation threats led to policy formulation for sustainable growth (Hossain, N., *et al.*, 2021). This awareness led to several initiatives taken by the international community such as the Stockholm Conference, Kyoto Protocol, Rio Convention, Montreal Protocol, the recent Paris Agreement, etc. (Jacquet and Jamieson, 2016).

Nowadays day consumption expansion is an impetus to economic growth, which ultimately, caused financial development in many countries. This persistent human pursuit has resulted in climate change. Therefore, various studies often report economic growth as key factor of environmental degradation (Bekun *et al.*, 2019 Firstly, growth and climate change relationship was deliberated and estimated with the name of the environmental Kuznets curve (EKC) premise offered by Grossman and Krueger (1995) which describes that initial stages of a nation's economic development increasingly degrade its environment but after a certain point of industrialization, it moderates. In the framework of developing economies, the policymakers suggest optimal trade-off between economic development and ecological protection. Economic development has been a complement of higher use of use of fossil fuels i.e. coal, natural gas, oil. The resulting emissions of CO2 have been a major cause of environmental degradation (Grossman, G. M., & Krueger, A. B. 1995). It is a fact that economic growth and urbanization are the drivers of rising energy demand, which ultimately, causes carbon emission. The reason is that individuals' movement from villages to cities for employment causes infrastructural disturbance and environmental issues. According to Founda and Santamouris (2017), urban zones are extremely susceptible to terrible changes in the environment because of urban-heat island impacts. Balogh, J. M., & Jámbor, A. (2020) noted that where trade-openness creates specialization opportunity, it also boosts up economic activities in the host economy which ultimately, damages the environment quality in the host economy.

Trade openness is an outcome of globalization in emerging economies. Theoretically, trade openness has three influential implications on greenhouse gasses emission i.e. a) scale effect; b) composition effect and c) technology effect (Antweiler *et al.*, 2020). The scale effect indicates that rising trend trade increases energy consumption, which ultimately, increases environmental pollution. The composition effect implies that comparative advantage theory helps countries to decide their production composition for their capital or labor -intensive industries. According to the factor endowment hypothesis (FEH), the latter is more contaminating than the first. The technology effect implies that trade is a key source of technology transfer among partner countries, which results in access to the use of more efficient practices of production.

Thus, this research aims at investigating the asymmetric impact of economic growth, and NODA on carbon emissions holding trade, FDI, and urbanization as control linear factors in case of Pakistan using the autoregressive distributive lag (ARDL) and non-linear autoregressive distributive lag (NARDL) bounds testing method. Although a plenty of literature exists over worldwide, this particular research work shall be a key source of knowledge for estimating an asymmetric nexus of the variables of interest and for understanding the sustainable development and implications.

LITERATURE REVIEW

A dearth of past literature supports the objectives of this research. Theoretically, EKC hypothesis described the non-linear relationship between economic growth and environmental sustainability (Grossman and Krueger, 1995). This theory firstly asserted an inverted U-shaped relationship between output growth and environmental degradation. Initially, economic growth contaminated the environment. Beyond a certain level, the use of technologies in the production process controlled the pollution. Purcel (2020) had given a wide-ranging literature on the EKC premise. Kılavuz and Dogan (2021) demonstrated output growth, industry, openness, and carbon emissions nexus over the period 1961–

2018 in case of turkey Turkey. They estimated a positive contribution of industry output and economic growth to CO2 emissions, while trade put insignificant impact on CO2 emissions. However, past studies estimated positive impact of trade on emissions because trade openness specifies the ways for the world economies to increase export level with increasing scale industries which ultimately leads to rising pollution (Jun *et al.*, 2020). Many studies posited rising pollution level with increased trade (Jun *et al.*, 2020. However, few studies estimated that an increase of trade openness had reduced pollution (Ghazouani *et al.*, 2020; Wang and Zhang (2021) perceived the positive relationship between trade openness and CO2 in low-income countries, while it is negative for middle- and high-income economies. Similarly, FDI and trade openness are estimated to have positive impact on emissions in developing nation with poor environmental regulations.

Past researches observed both directions; positive and negative in the relationship of economic income with pollution. Past studies have mostly examined the nexus of economic growth with environment after the introduction of the most popular EKC premise by Grossman and Krueger (1995). Many studies estimated a positive association between growth and pollution Alshehry and Belloumi, 2015; Menyah and Wolde-Rufael, 2013). Rajpurohit and Sharma (2021) also observed a moderate impact of output growth and financial development on carbon emissions. also examined the positive impact of natural resources and economic growth on emissions for Pakistan over 1972–2016. They differently measured a significant and negative influence of population density, CO2 emissions and deforestation on the economic growth. estimated the curvilinear nexus between environmental degradation and growth in India over 1971–2014. They concluded negative effects economic growth, energy consumption, and financial development on the environment. Various past studies looked into urbanization influence on the environment quality (Chen, R., *et al.*, 2023). Nathaniel and Khan, (2020) and Khan *et al.* (2022) concluded that the influence of urbanization on climate change varied from country to country worldwide. Liu and Bae (2018) investigated a considerable negative impact of urbanization on sustainable environment. Al-Mulali and Ozturk (2016) discussed the negative impact of industry, trade, urbanization, and energy on the environment using EKC premises. Li and Lin, (2015) and Pata (2018) concluded negative impact of urbanization on carbon emission implying that optimal usage of urban infrastructures had reduced energy consumption, reducing both carbon emissions and energy demand.

Pakistan is noted as the developing economy of the world and it is also among the higher carbon emitter countries. With the spirit of high industrial and output growth, the emissions are substantially growing because of relying on fossil fuels. Due to this scenario in Pakistan and other developing economies, the world is susceptible to environmental changes and faces threats of rising sea levels, droughts, floods and health risks. Therefore, this research aims at finding the impact of trade, output growth, FDI, urbanization, and NODA on carbon emissions in the context of Pakistan.

This research is the hottest and closely associated with the literature on environmental sustainability in Pakistan. None of the past manuscripts has investigated the influence of NODA the environmental degradation in case of Pakistan except Lee *et al.* (2020) and Choi & Oh, (2022) in case of Korea and Magnolia, respectively. However, the discussion on trade, economic growth, and FDI to response emissions is common in other studies like Kılavuz and Dogan (2021) has discussed the same factors except NODA, but their work only confines to Turkey. As a result, this study is the first one estimating this nexus for Pakistan, an addition to the knowledge of manufacturing, economic development, trade and environmental sustainability. This work investigated ODA, economic growth and carbon emissions nexus based on direct and indirect mechanism for 30 recipient economies during 1993-2017. It used an impact, population, affluence, and technology (IPAT) model. The empirical outcomes showed that ODA directly and indirectly helped in mitigation of carbon emission for the given panel. Furthermore, the estimation outcomes validated the existence of EKC premise for economic growth and trade showing that output growth potentially mitigated the environmental degradation in the recipient countries. Therefore, the bilateral cooperation, through ODA and the supportive policy, should make an effort to promote economic development and mitigation of environmental degradation in developing countries.

investigated the EKC hypothesis considering trade, urbanization, energy consumption, and financial development factors in case of Turkey during 1960-2013. The bounds test and the short-term outcomes confirmed the EKC premises for the variables of interest. Keeping in view of estimated outcomes, this study had proposed "polluter pays" tool to raise the awareness of sustainable environment. Chen, R. *et al.(2023)* and Khan *et al.* (2022) also investigated urbanization carbon emissions nexus in case of Pakistan using ARDL approach. The regression outcomes endorsed that carbon emission had increased with an increase of urbanization. Further, the existence of short-run association verified the long term outcome. Thus, this research suggests the development of energy-efficient urban units to reduce carbon emissions.

reported that where the consumption of fossils fuels and urbanization had produce carbon emission, it had also degraded environmental quality. observed that severe smoke arisen from the factories, and the use of wood being a part of energy source increased the carbon emission which had a destructive influence on the economy. The abstract from the above two literature focused on the need of new area of research named by sustainable growth. These studies

estimated the significant impact of tradition energy use and urbanization on carbon emissions.

estimated the impact of economic growth and trade on carbon emission in the economy of Pakistan during 1980-2014. It used Johansen co-integration and error correction methodology for long and short runs dynamics among variables of interest. Empirical outcomes indicated that initially, rising trend of growth led to higher carbon emission but after a while, an increase of growth resulted in carbon emission reduction. This result validated the premise of EKC. Further, this study showed significantly positive impact of energy use and trade on environment pollution in log run. This conclusion implies that Pakistan can protect its environment by using environment friendly energy resources and trading those goods which helped to sustain the environment. Another study discussed the impact of trade and economic growth on carbon emissions in the context of Pakistan over 1980–2014. The key findings of this research confirmed EKC premise while trade response to carbon emission was significantly positive.

Another explored the nexus of energy use and output growth with carbon emissions for Pakistan during 1971-2019 using the ARDL bounds test and VECM. The bounds test outcomes confirmed the co-integration among the studied variables. Empirical outcomes showed energy use, output growth, and trade significant indictors of the climate change in both time periods while urbanization was not significant in the long run. Further, this study has been constructed as follows. Part 2 deals with the data and method, part 3 consists of results and part 4 contains conclusion and suggestions.

MATERIALS AND METHODS

This study will estimate the following functional form to estimate economic growth, trade, urbanization, official development assistance and carbon emission nexus in case of Pakistan over the period 1995-2022 following (Choi, S., Munkhsaikhan, Z., and Oh, J. 2022).

CO_2= f (GDP growth, trade, urban population, net official development, FDI)

The generalized linear form of the prior functional form can be represented as follow:

$$lnCO_{2i,t} = \beta_0 + \beta_1 lnGDP_t + \beta_2 lnURBAN_t + \beta_3 lnTRADE_t + \beta_4 lnNOD_t + \beta_5 lnFDI_t + \mu_t \quad (1)$$

Where CO_2 is Carbon dioxide emissions, GDP is gross production growth, URBAN is urbanization, TRADE is international trade, NOD is net official development assistance and FDI is foreign direct investment. β_1 to β_5 are long-run elasticities of the corresponding independent factors and μ_t is the error term. Annual time series data for the variables of the interest are taken from WDI (world development indicator) over the period 1996 to 2022 for Pakistan. Total carbon dioxide (CO2) emissions in metric ton are used to measure environmental pollution. FDI is measured in dollar. Some missing values in the data are generated by extrapolation technique (Rubin 1976). It improves the data validity and quality for the missing values (Hao *et al.*, 2021). The fundamental goal of this part of the study is to clarify the methodologies which help to gather, investigate and understand the information. Firstly, unit root test looks not essential to estimate Auto-Regressive Distributed Lag (ARDL) model because it can test the existence of co-integration between a set of variables having 0 or 1 or mixed order of integration. Secondly, time series data of often suffers unit root problem. Therefore, before application of the empirical methods, the use of unit root test is necessary to examine the unit root problem in the given series. However, the ARDL Bound Testing method presented by Pesaran, M. H., & Shin, Y. (2002) who requires that no variable should be stationary at order 2. Otherwise, this approach will give deceptive results of such data. Therefore, the stationary analysis is necessary to continue the next level of analysis. Augmented Dickey Fuller and the Phillips Pearson Unit root tests will be used to verify whether the series are stationary or not and whether they are integrated at order 0, 1 or 2 to verify the probability of running ARDL. The linear specification of ARDL is introduced by Pesaran, M. H., & Shin, Y. (2002) due to having additional advantages over other time series econometric techniques. This method estimates Long-run and short-run effects in one step. To avoid the problem of spurious regression, Pesaran et al. (2001) recommend two tests i.e. F-Bound-test and ECM for co-integration confirmation. Expected stationary outcomes have proposed the use of ARDL (autoregressive distributed lagged model) to see the long term impact of independent factors on CO2. By estimation of this model, this study reported unbiased empirical outcomes. Thus, this study will estimate the following ARDL model.

$$\triangle lnCO_{2i,t} = \beta_0 + \sum_{i=1}^{n} \mu_1 \triangle lnCO_2 t- i+ \sum_{i=0}^{n} u_2 \triangle lnGDPt - i+ \sum_{i=0}^{n} u_3 \triangle lnURBANt - i+ \sum_{i=0}^{n} u_4 \triangle lnTRADEt - i+ \sum_{i=0}^{n} \mu_5 \triangle lnNODt - i+ \sum_{i=0}^{n} \mu_6 \triangle lnFDIt - i+ \gamma_o lnCO_2 t - 1+ \gamma_1 lnGDPt - 1+ \gamma_2 lnURBANt - 1+ \gamma_3 lnTRADEt - 1+ \gamma_4 lnNODt - 1+ \gamma_5 lnFDIt - 1+ e_t \quad (2)$$

Further, ARDL specification has been extended to non-linear ARDL to express asymmetric nexus of the key variables of interest following Stern, D. I., Common, M. S., & Barbier, E. B. (1996).

$$\triangle lnCO^2{}_{i,t} = \beta_0 + \sum_{i=1}^{n} u_1 \triangle lnCO^2 t - i + \sum_{i=0}^{n} u_2 \triangle lnPOSGDP\, t - i + \sum_{i=0}^{n} u_3 \triangle lnNEGGDP\, t - i + \sum_{i=0}^{n} u_4 \triangle lnURBANt - i + \sum_{i=0}^{n} u_5 \triangle lnTRADEt - i + \sum_{i=0}^{n} u_6 \triangle lnPOSNODAt - i + \sum_{i=0}^{n} u_7 \triangle lnNEGNODt - i + \sum_{i=0}^{n} u_8 \triangle lnFDIt - i + \gamma_o lnCO_2 t - 1 + \gamma_1 POSGDPt - 1 + \gamma_2\, NEGGDPt - 1 + \gamma_3 lnURBANt - 1 + \gamma_4 lnTRADEt - 1 + \gamma_5 \ln\, POSNODAt - 1 + \gamma_6 lnNEGNODAt - 1 + \gamma_7 lnFDIt - 1 + e_t \quad (3)$$

The " △ " is symbol of the change and indicates the first difference, u_1 to u_8 are the long term coefficients of regressors while $\boldsymbol{\gamma_o to \gamma_7}$ are the short run elasticity. Furthermore, the constant term is $\boldsymbol{\beta_0}$ and e_t is the error term. This study has incorporated trade to deal with open economy.

RESULTS AND DISCUSSION

The empirical outcomes regarding the impact of trade and economic growth on environmental pollution are discussed in detail in this section. In Table 1, ADF unit root statistical values reveal that all given series are integrated at order 1 except urbanization that is integrated at both orders. After unit root problem investigation, this study firstly infers to apply ARDL approach for further estimation measurement. Secondly, the research problem has been solved with the application of NARDL estimation method.

Table 2 describes the estimated coefficients of the aforementioned ARDL model in case of Pakistan. The coefficient of the lagged CO_2 depicts highly significant and positive impact on current carbon emissions. This outcome implies the continuous use of fossil fuels and high level of climate threats. The same is supported by Nathaniel and Khan, (2020). These outcomes also indicate that 1% increase in FDI in the long run has caused the rising trend of CO2 emission up to 0.12% at p<0.05 due to more share of non-renewable energy resources in the total energy consumption by foreign investors. This outcome is also aligned with Trade factor has significantly reduced CO2. The reason is that the major share of imports contains efficient energy sources which have significantly improved the quality of climate. This outcome is also supported by Jun et al., (2020). Empirical outcomes show that GDP growth, NODA, and urbanization are surprisingly insignificant to cause CO2 emissions. ARDL model has been extended with NARDL model to deal with the main objective of the study i.e. asymmetric impact of GDP and NODA on environment quality. Estimation of NARDL only validates the existence of u-shaped relationship between NODA and CO2 about at 5% significance level. This outcome shows that initially, 1% rise of NODA has resulted in approximately 0.12% reduction in CO2 High rate of CO2 emissions, later on, a 1% reduce of NODA has significantly caused 0.15% downturn in CO2 in Pakistan. This non-linear nexus is the key feature of this research while negative linear relationship is also estimated by Lee et.al. (2020). At the first phase, CO2 reduction due to positive changes in NODA can be due to following channels. Firstly, the use of NODA in the funding of renewable energy plans in developing economies may increase investments in wind, solar, hydroelectric, and other green energy projects and help them to move from non-renewable fuels to renewable fuels and reduce their CO2. Secondly, rising NODA can be an initiative to expand energy efficiency in developing states. This may be involved updating structure, encouraging energy-efficient tools, and implementing guidelines that stimulate sustainable practices, finally leading to lower energy use and CO2 reduction. Therefore, Michaelowa and Michaelowa (2007) also argue that the changing function of NODA due to the rising climate changes. Thus, Organization for Economic Co-operation and Development (OECD 2009) also recommended the integration of environmental change adaptation into development co-operation. At the second phase, negative changes in NODA like reductions in this funding may potentially result in adverse climate problems including higher CO2 emissions. The reason is that firstly, a cut in

Table 1. Estimated outcomes of Augmented Dickey-Fuller Statistic.

Variables	Stationarity at level		Stationarity at first difference	
	ADF t-Statistic	Prob.*	ADF t-Statistic	Prob.*
CO2	-1.138953	0.6837	-4.115731	0.0042
FDI	-1.606260	0.4658	-4.221583	0.0030
GDP growth	-0.036851	0.9468	-3.783198	0.0085
LnTRADE	0.226627	0.9693	-3.678644	0.0108
LnNODA	-2.363351	0.1613	-4.917077	0.0007
URBAN POP	-3.703061	0.0031	-4.193655	0.0377

Table 2. Empirical Outcomes of ARDL.

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
CO2 (-1)	0.511426	0.267702	1.910435	0.0721
FDI	0.118207	0.047184	2.505240	0.0221
LNTRADE	-0.450071	0.244350	-1.841909	0.0820
NODA1	-0.048419	0.048853	-0.991103	0.3348
URBAN POPULATION GROWTH	-0.009178	0.036359	-0.252419	0.8036
GDP	0.541903	0.420703	1.288090	0.2140
C	-1.513566	3.112367	-0.486307	0.6326

Table 3. Empirical Outcomes of NARDL

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
CO2 (-1)	0.287722	0.198589	1.448832	0.16560
GDP_POS	3.656597	0.989655	3.694819	0.00180
GDP_NEG	-7.538510	7.226512	-1.043174	0.31150
LNTRADE	-0.453997	0.206779	-2.195568	0.04230
LNNODA1_POS	-0.115196	0.055976	-2.057938	0.05530
LNNODA1_NEG	0.156964	0.075893	2.068241	0.05420
URBAN_POPULATION GROWTH	-0.148683	0.083245	-1.786092	0.09190
C	10.033350	4.573444	2.193827	0.04240
R-squared	0.836362	Mean dependent var		0.72586
Adjusted R-squared	0.810158	S.D. dependent var		0.08386
S.E. of regression	0.025136	Akaike info criterion		-4.27466
Sum squared resid	0.010741	Schwarz criterion		-3.88462
Log likelihood	61.433260	Hannan-Quinn criter.		-4.16648
F-statistic	35.733520	Durbin-Watson stat		2.03270
Prob(F-statistic)	0.000000			

Table 4. NARDL Error Correction Regression and Bonds Test Statistics

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CointEq (-1)*	-0.712278	0.100632	-7.078063	0.0000
R-squared	0.661554	Mean dependent var		0.007553
Adjusted R-squared	0.661554	S.D. dependent var		0.036364
S.E. of regression	0.021155	Akaike info criterion		-4.834661
Sum squared resid	0.010741	Schwarz criterion		-4.785906
Log likelihood	61.43326	Hannan-Quinn criter.		-4.821138
Durbin-Watson stat	2.032696			
F-Bounds Test		**Null Hypothesis: No levels relationship**		
Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
F-statistic	4.435846	10.0%	1.99	2.94
k	6	5.0%	2.27	3.28
		2.5%	2.55	3.61
		1.0%	2.88	3.99

NODA funding can slow down the acceptance of wind, solar, and other renewable tools, obstructing the efforts to decrease the trust on fossil energies and consequently leading to rising CO2. Secondly, a cut in NODA may discourage the funding for energy efficiency plans and ultimately, may lead to use of inefficient fuels and result in higher CO2.This asymmetric association may firstly be estimated in this research work.

Among empirical results, positive changes in GDP growth is only positively associated with CO2 with a highly significant p-value while negative changes in GDP growth is negatively related with CO2, but this direction of relationship is insignificant. It concludes that GDP growth has only linear relationship with CO2. This outcome is contrasted with the following studies i.e. Yu, Y., et al. (2023), Alshehry and Belloumi, (2023) . Remaining factors are linearly estimated using NARDL. Among the results, trading activities are significantly negative to affect CO2 due to more imports of energy efficient technologies. This outcome is aligned with Rising urbanization has significantly reduced CO2 due to employing green urban strategies in developing economies. This outcome is also supported by Chen, R., *et al.* (2023) and Khan *et al.* (2021) while it is contradicted to Nathaniel and Khan, (2020) and Liu and Bae (2018). The value of adjusted R^2 reveals 81% CO2 is explained by these key factors. About near to 2 D.W values shows no heteroscedasticity problem in the model. The significant F-statistics implies significant contribution of the independent factor in CO2.

The bounds test has helped to confirm the existence of the long-run nexus between the variables of interest as discussed in the empirical model. The null hypothesis of this method states no co-integration between the variables of interest. If the calculated value of F-statistic is higher than critical value of upper bound, it refers to the existence of co-integration relation in the model. If the calculated F-statistic is less than the critical value of lower bound, it means no co-integration. However, if the F-statistic is within the critical limits, it is considered as inconclusive. The empirical result of this paper reveals that the calculated F-statistics is higher than the

critical values at the upper bound with a p<0.01. Thus, the null hypothesis of no long-run association between carbon emissions and other variables is rejected. This outcome shows that there is a co-integration between carbon emissions, trade openness, NODA, FDI, urbanization and economic growth. This empirical verification allows estimating the long-run coefficients of the model. Where Error correction model gives the solution of short run association of the variables of interest, it also implies the existence of long run association. The estimation of ECM model concludes that the coefficient of cointEq i.e. -0.72 with p=00 refers to the fact that any disequilibrium in the short run has been corrected in the long run. Among diagnostic tests, Breusch-Godfrey Serial Correlation test statistics leads to accept the null hypothesis of no serial correlation and Breusch-Pagan-Godfrey test statistics refers to accept the null hypothesis of no Heteroskedasticity.

Table 5. Breusch-Godfrey Serial Correlation LM Test.

F-statistic	0.228984	Prob. F(2,15)	0.7981
Obs*R-squared	0.740667	Prob. Chi-Square(2)	0.6905

Table 6. Heteroskedasticity Test: Breusch-Pagan-Godfrey.

F-statistic	0.725513	Prob. F(7,17)	0.6529
Obs*R-squared	5.750581	Prob. Chi-Square(7)	0.5692
Scaled explained SS	5.196938	Prob. Chi-Square(7)	0.6359

***Conclusion*:** This study investigates the impact of official development assistance (ODA), economic growth, trade, and urbanization on CO2 emissions in Pakistan from 1995 to 2022. Utilizing ARDL and NARDL methodologies, it finds a significant link between ODA and CO2 reduction, highlighting the importance of ODA in addressing environmental challenges. Results show that while FDI and GDP growth increase CO2 emissions, trade and urbanization contribute to emission reduction. Moreover, the study reveals a U-shaped relationship between ODA and CO2 emissions, emphasizing the need for nuanced policy approaches to support sustainable development. Integrating ODA into policy reforms and capacity-building programs emerges as a key strategy for promoting lower CO2 development paths and mitigating environmental risks.

By focusing on the asymmetric effects of ODA and GDP growth on CO2 emissions, this research underscores the potential of international assistance in driving positive environmental outcomes. Positive changes in ODA are associated with CO2 reduction through investments in renewable energy and energy efficiency initiatives, while reductions in ODA funding may exacerbate climate challenges. These findings underscore the importance of aligning development assistance with environmental objectives and integrating environmental considerations into development cooperation efforts. By leveraging ODA to promote sustainable practices and build resilience to environmental challenges, Pakistan can pave the way for lower CO2 development trajectories and foster effective policy responses to environmental threats.

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***Availability of data and material*:** We declare that the submitted manuscript is our work, which has not been published before and is not currently being considered for publication elsewhere?

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